Proposal for Level 2 Calorimeter Trigger Upgrade

Mary Convery

for

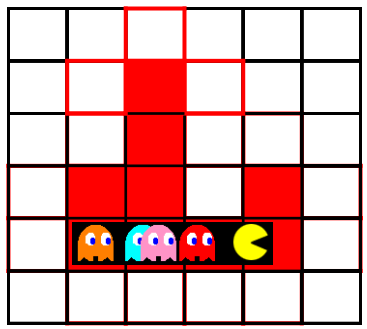
A.Bhatti, M.Convery, G.Cortiana, M.Dell'Orso, G.Flanagan, H.Frisch, P.Giannetti, O.Gonzalez, M.Jones, T.Liu, D.Lucchesi, M.Piendibene, L.Ristori, L.Rogondino, V.Rusu, L.Sartori, S.Torre, V.Veszpremi, S.M.Wang

Rockefeller, Padova, Pisa, Purdue, U.Chicago, Madrid, Fermilab, Frascati, Academica Sinica

Level-2 Jet clustering and MET in the current system

Jet clustering at Level 2

- Current jet clustering is implemented in hardware using a simple algorithm from Run I
  - The algorithm finds a seed (threshold 3GeV), then attaches any tower above the shoulder threshold (1 GeV) which touches any other tower in the cluster



"Pac-Man"

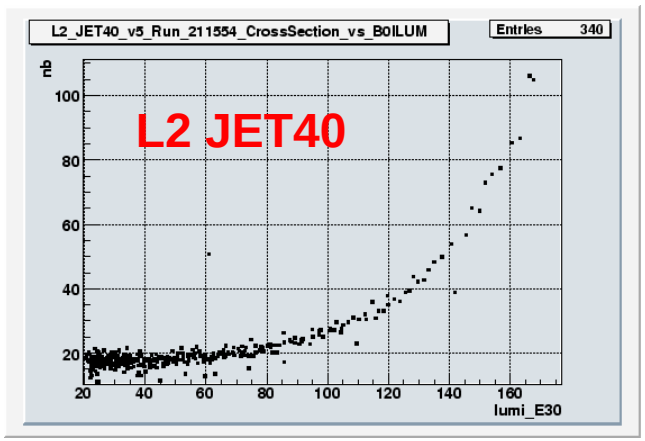
  - The clustering steps through η,ϕ – bias seed
  - The cluster location is simply taken to be the seed location

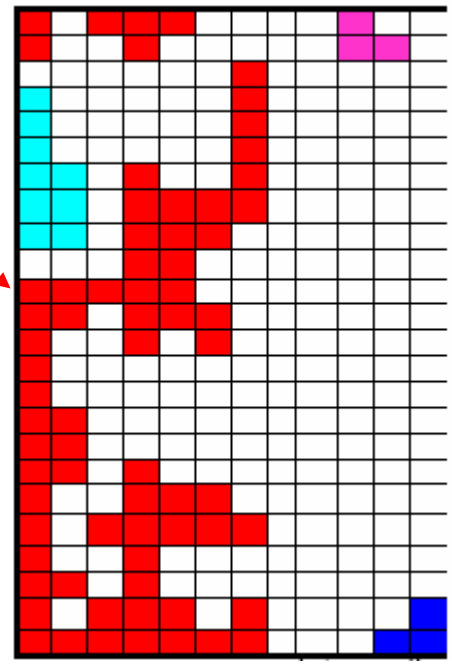
L2 jet clustering breaks at high luminosity

- Underlying Event energy increases due to pile-up interactions and possibly beam backgrounds

  →Towers boosted above threshold: huge number of towers clustered together

- Jet trigger cross sections grow rapidly with luminosity



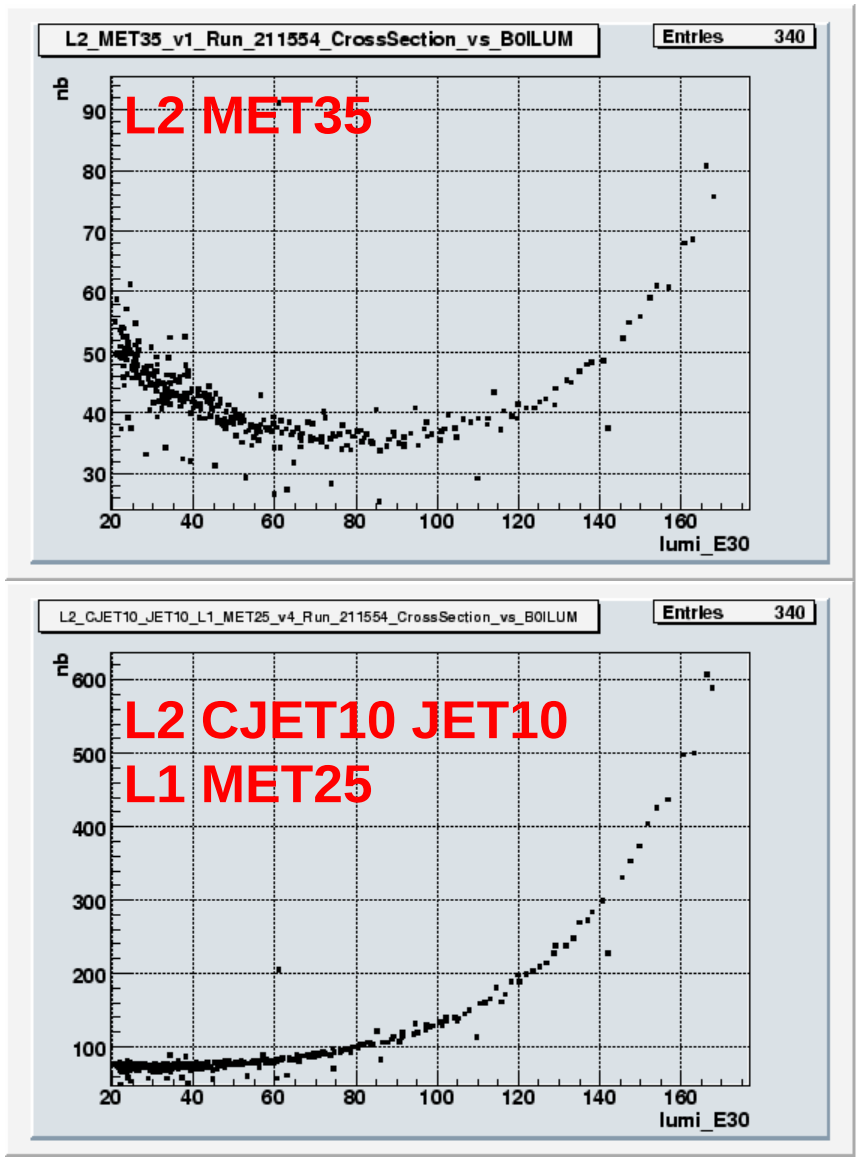


?

- Cluster E_T, η, ϕ, ... even poorer match to true jets

MET triggers at high luminosity

- Currently, MET is not calculated at L2
- Simply uses L1 MET (calculated using 8-bits of the 10-bit calorimeter trigger tower E_T information)
- Cross sections grow rapidly with luminosity
  - Fake MET due to poor resolution



Why should I care?

- Jet triggers used for jet energy/resolution, *b*-tagging studies – prescaled beyond usefulness?
- Multi-jet triggers (Higgs, top) lose efficiency as jets are merged together
- MET triggers (Higgs, new physics searches) not able to be kept at highest luminosities – can't control cross section without losing trigger efficiency / signal acceptance
- Taking up bandwidth (with junk) from the triggers you do care about

Performance of L2 jet and MET triggers in the current system

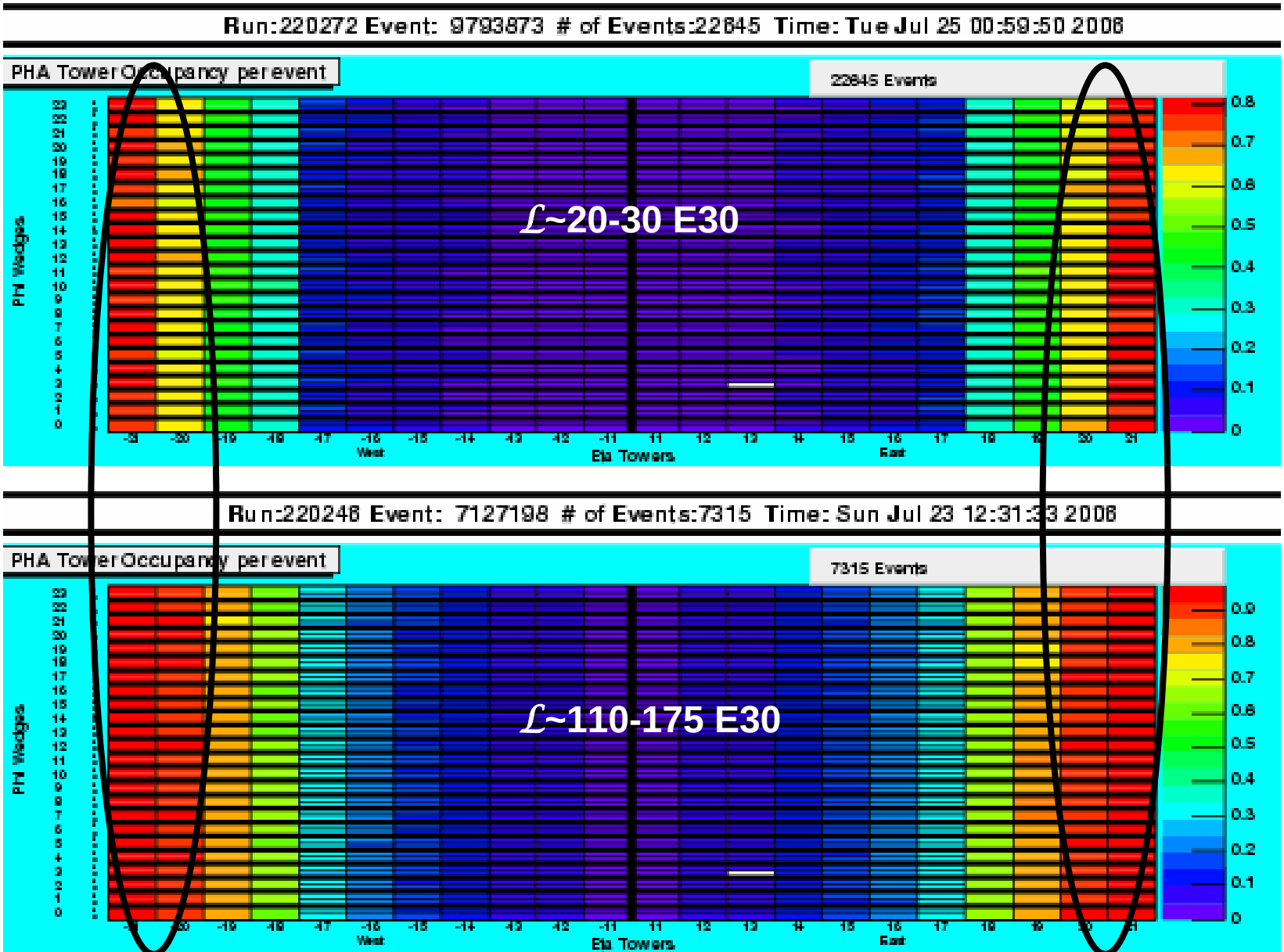
The inclusive jet triggers

- L1_JET5_PS_50
  - L2_JET15_PS25
    - Jet20
  - L2_JET40
    - Jet50
- L1_JET10 (→ PS8)
  - L2_JET60_PS8 (→ no PS)
    - Jet70
- L1_JET10 (→ L1_JET20)
  - L2_JET90
    - Jet100

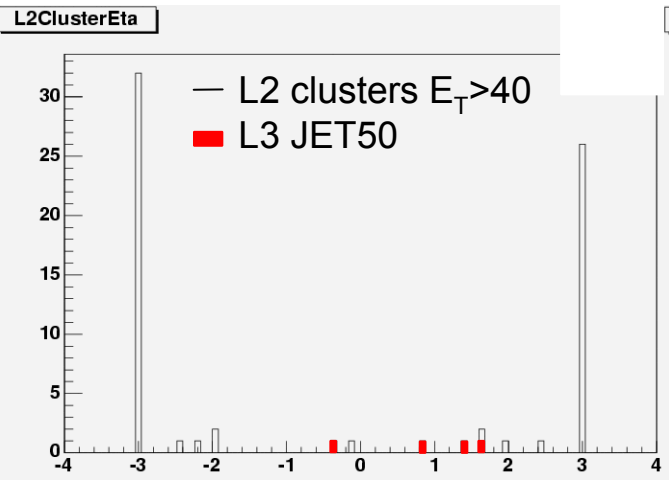
"A brief history of recent L2 Jet trigger -- the rise and fall, then rise …"

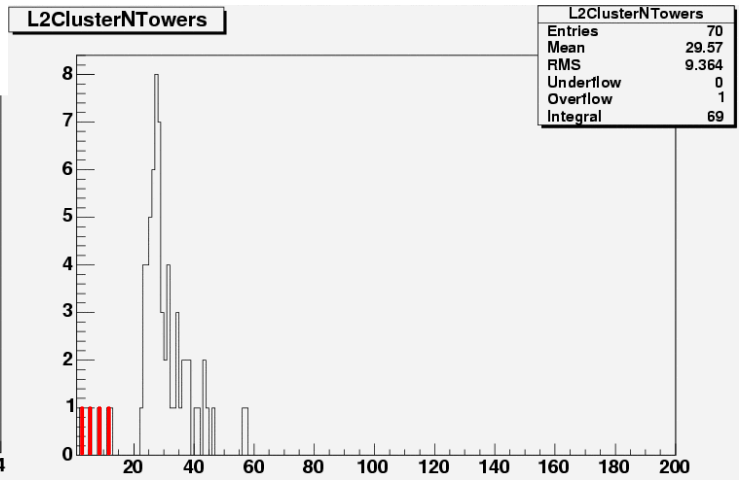
- More than a year ago, it became clear that the L2 Jet triggers had a large growth term with luminosity. We knew it was due to activity in the Ring-Of-Fire (highest-$|\eta|$ colorimeter towers)
- Early last summer, we learned that it was due to too many shoulders in the ROF to cause L2CAL finding large/huge fake clusters (hardware algorithm limitation)
- Once the shoulders are removed from ROF, the situation improved dramatically…(~ up to 100E30 back then)
- As luminosity went higher, the high growth term came back again…

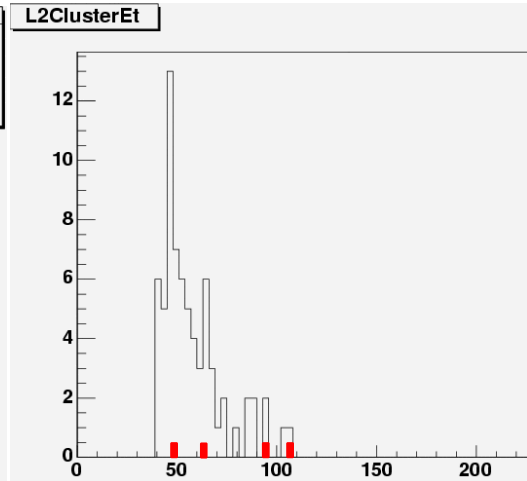
The Ring-of-Fire



First proof of the ROF in jet triggers





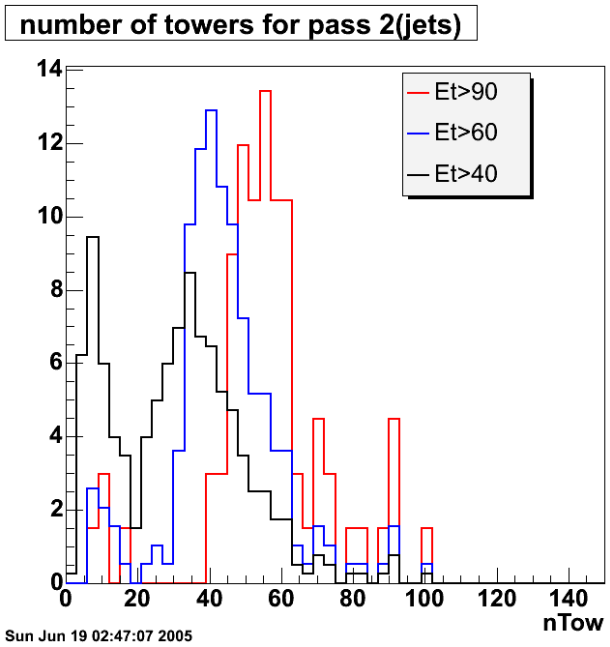


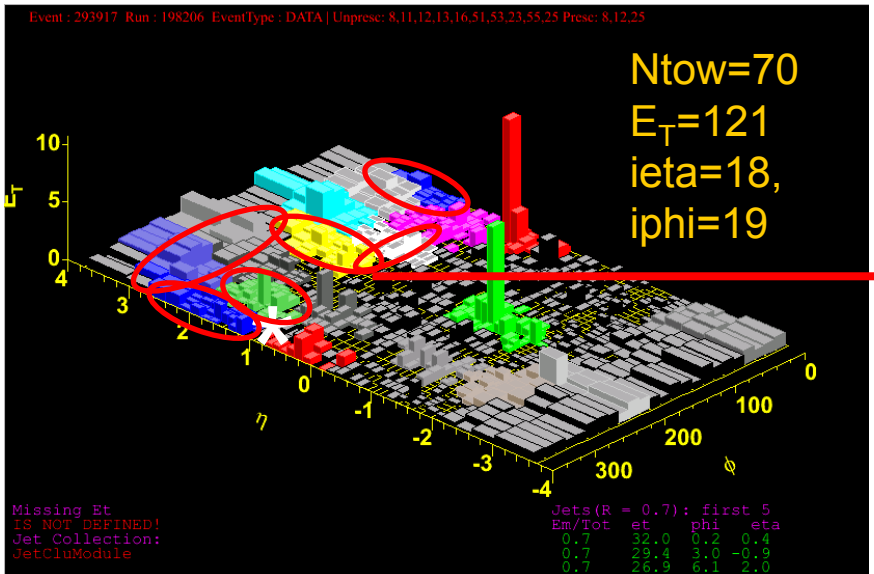
- Observed in Feb 2005
- ST5 data run 192360 ($\mathcal{L}$~101-112 E30, L2 J40 rate 49 Hz)
- 80% L2 clusters E_T>40 have $|\eta|$=3, >20 towers in cluster

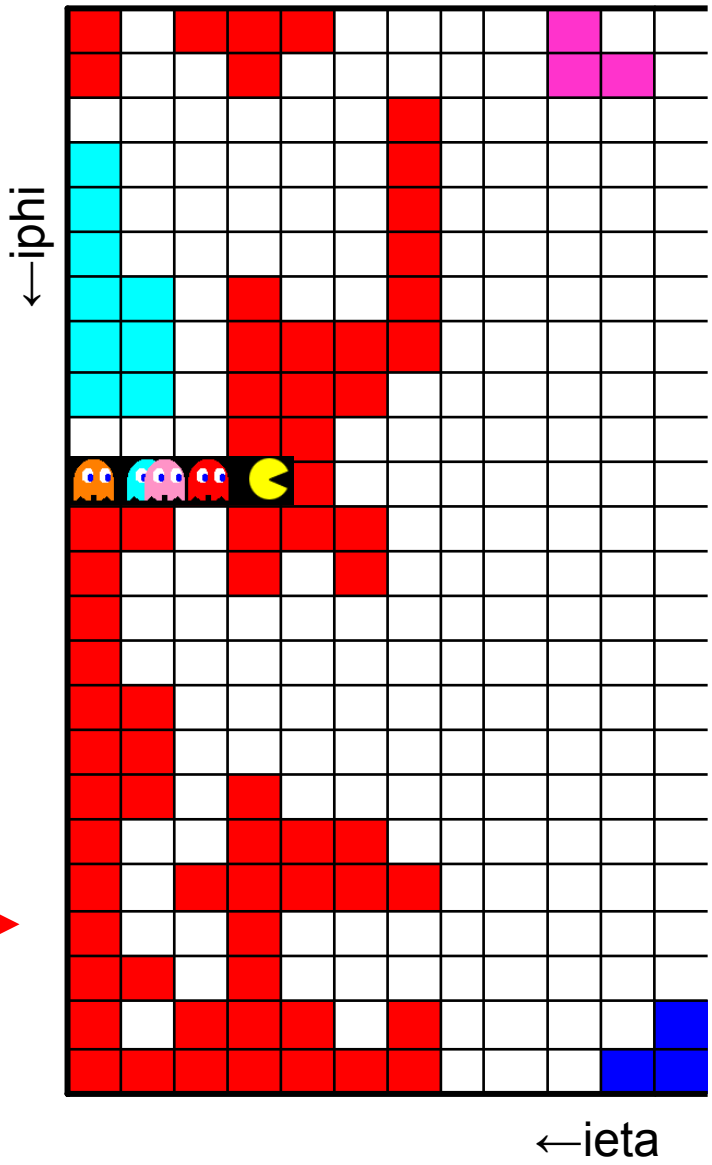
ROF removal

- It was decided to remove the highest-$|\eta|$ trigger towers from the L2 clustering – as seeds
- L2 jet rates were still high
- Then we observed the following $\rightarrow$
- It was decided to remove the highest-$|\eta|$ trigger towers from the L2 clustering as shoulders too

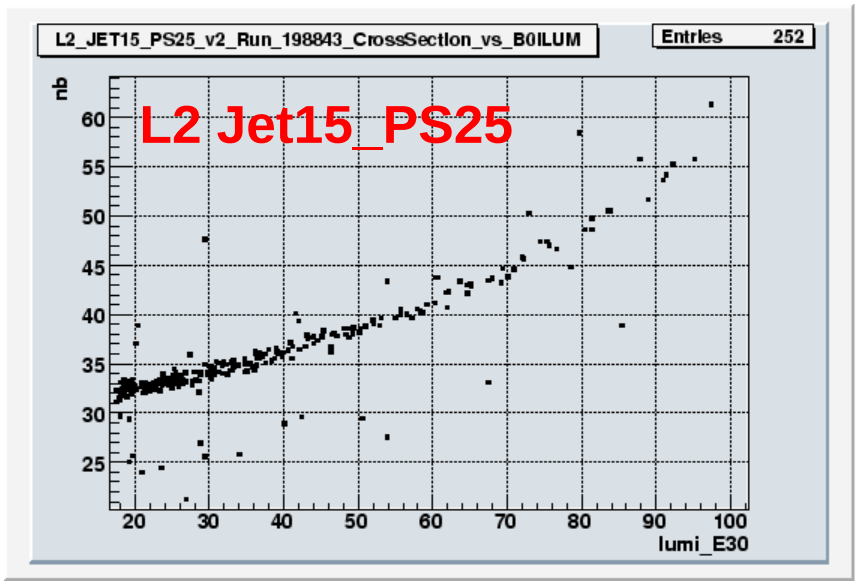
Second proof of the ROF

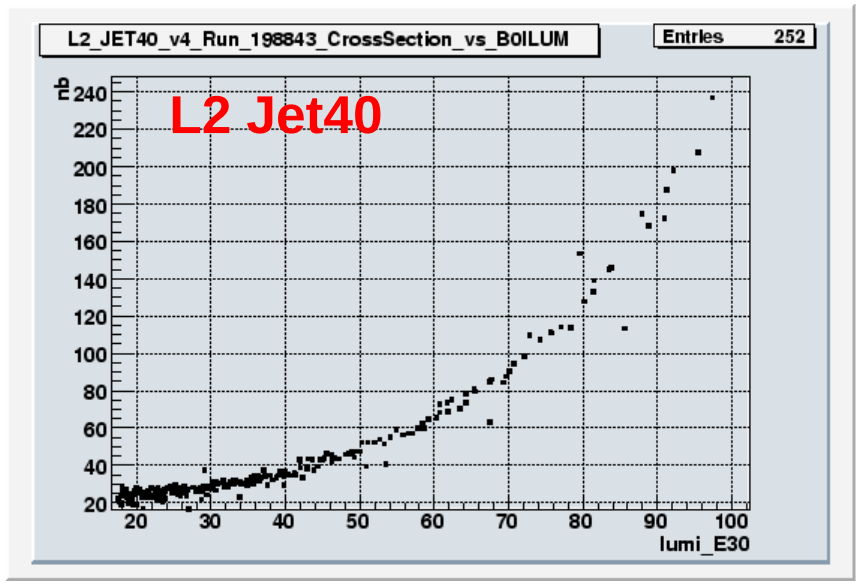


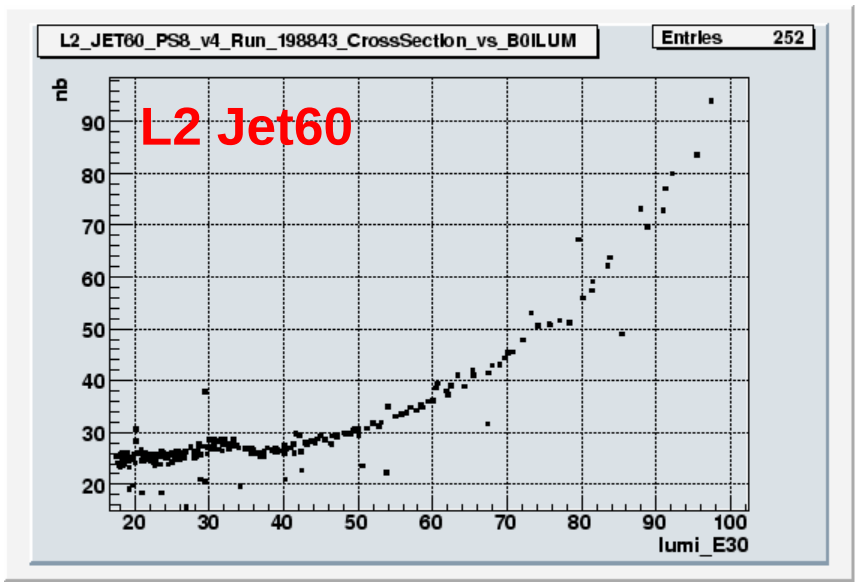


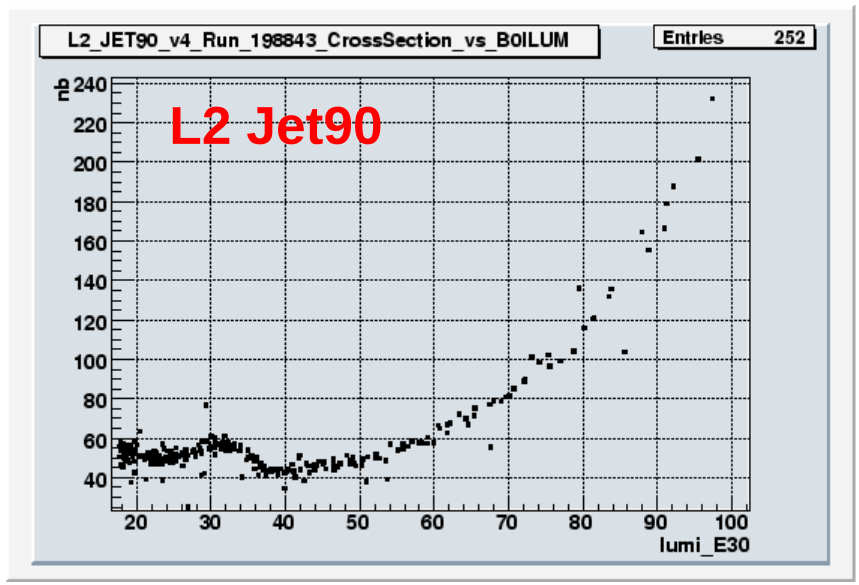


Jet trigger cross sections before ROF removal

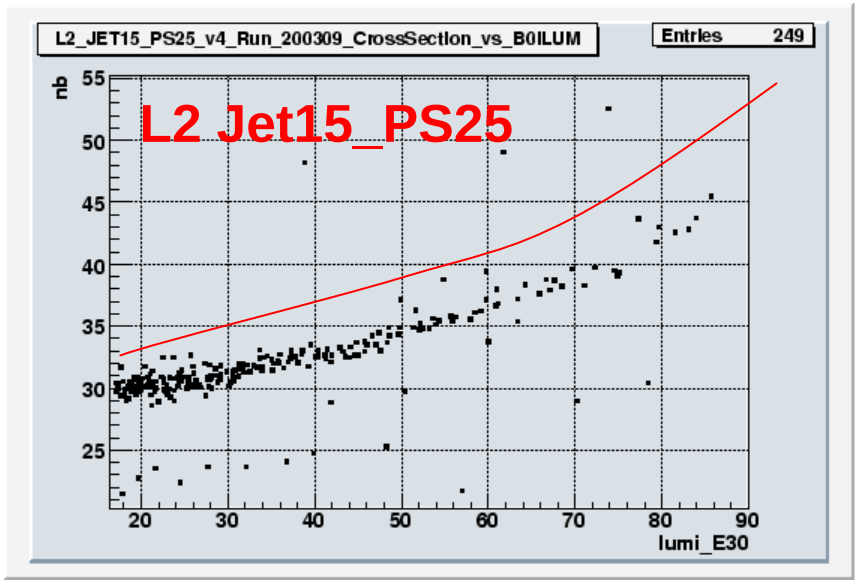


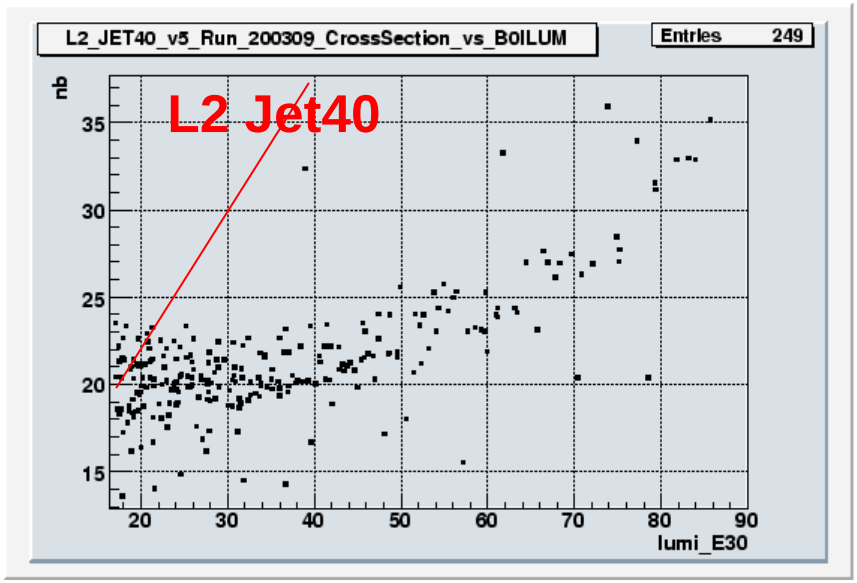


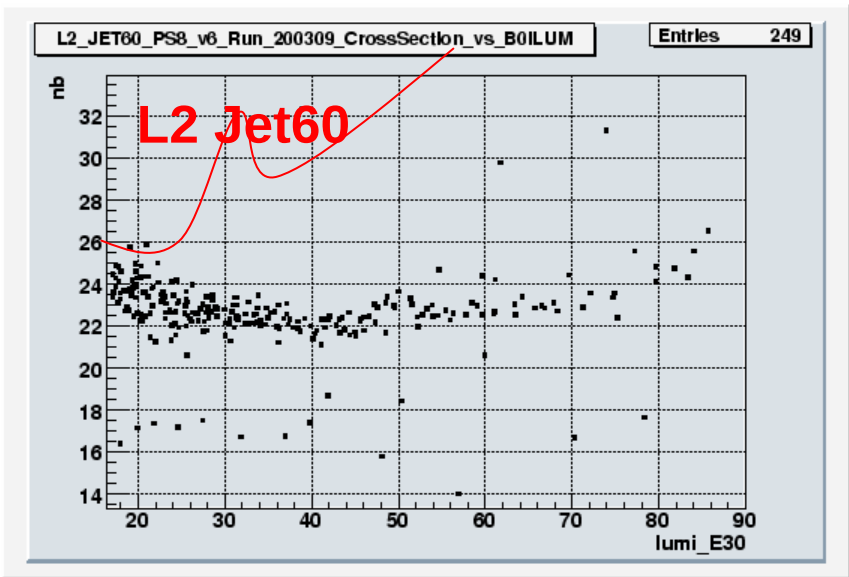


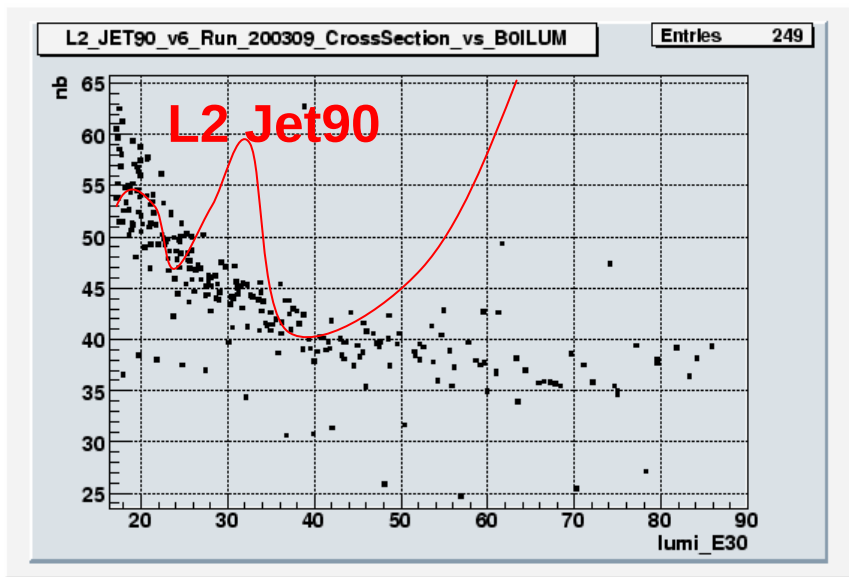


Jet trigger cross sections – no ROF

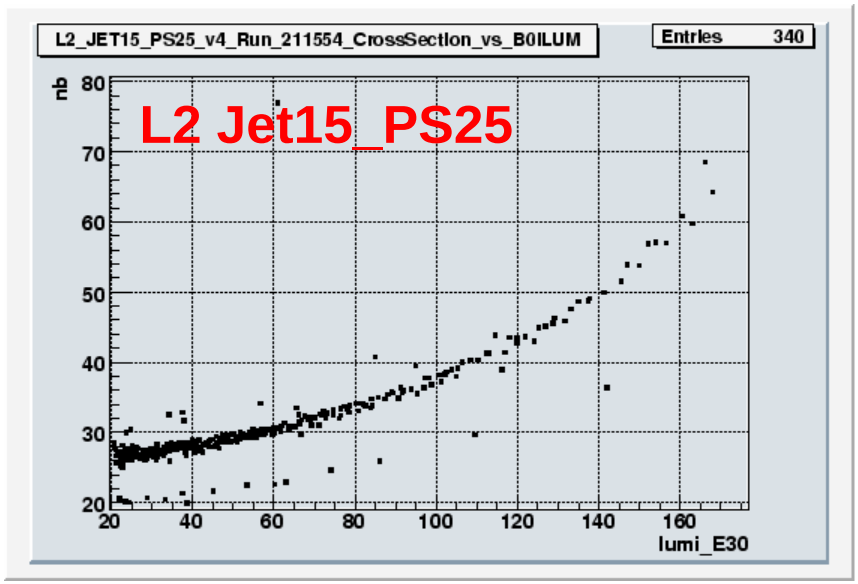


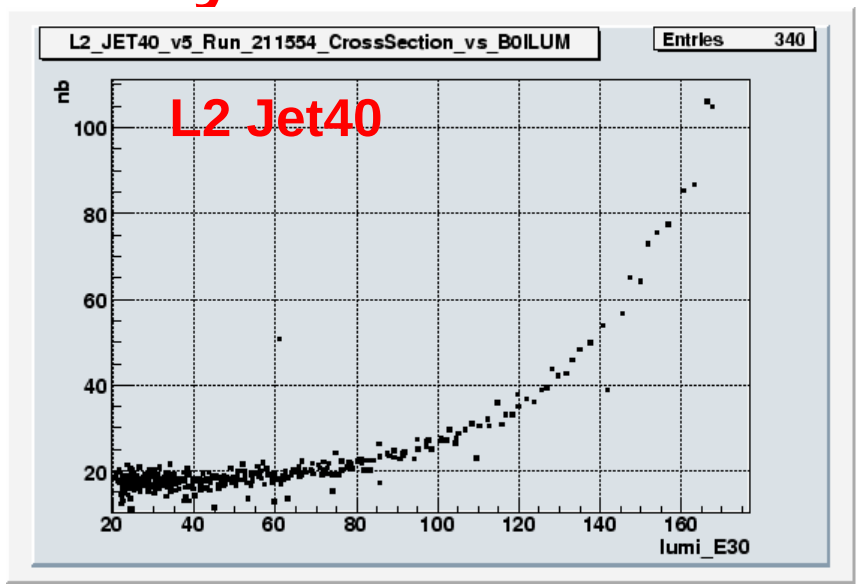


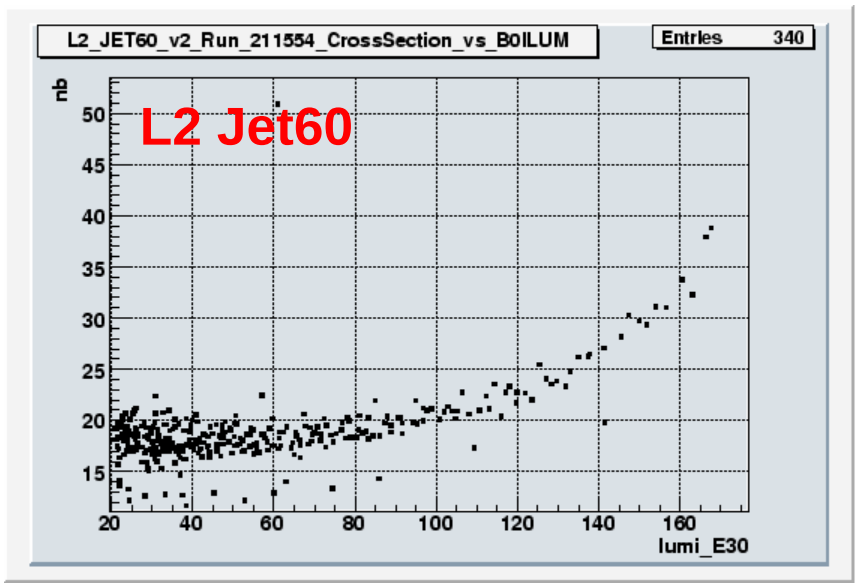


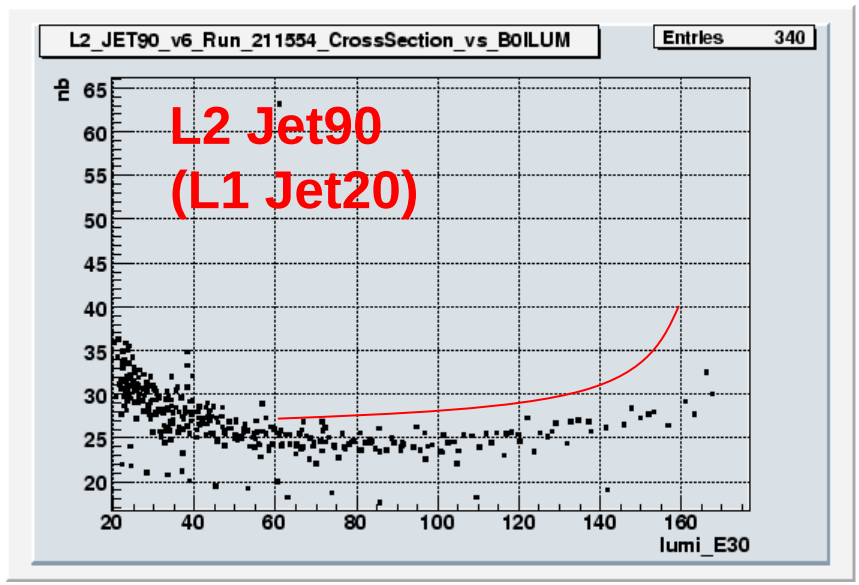


Jet trigger cross sections at higher luminosity







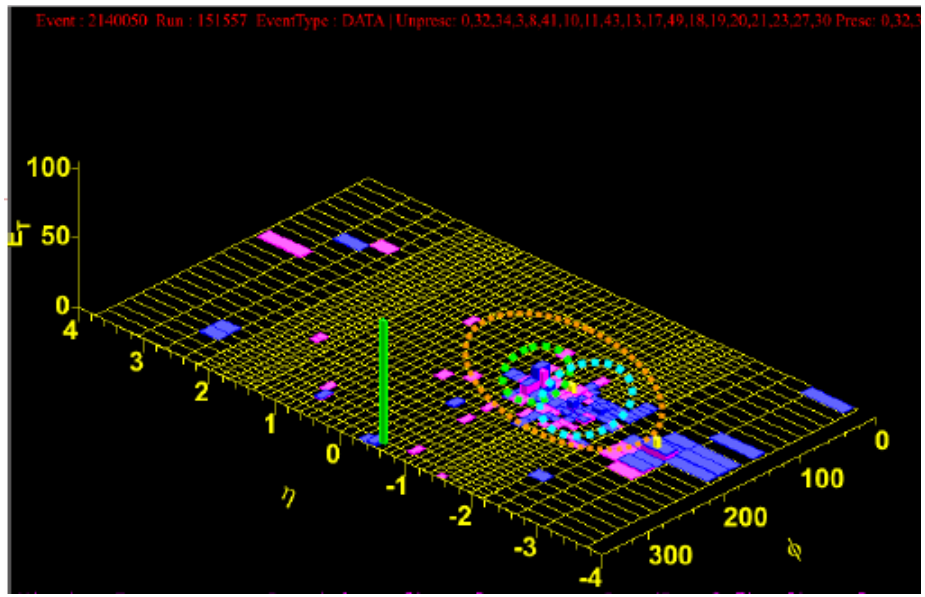


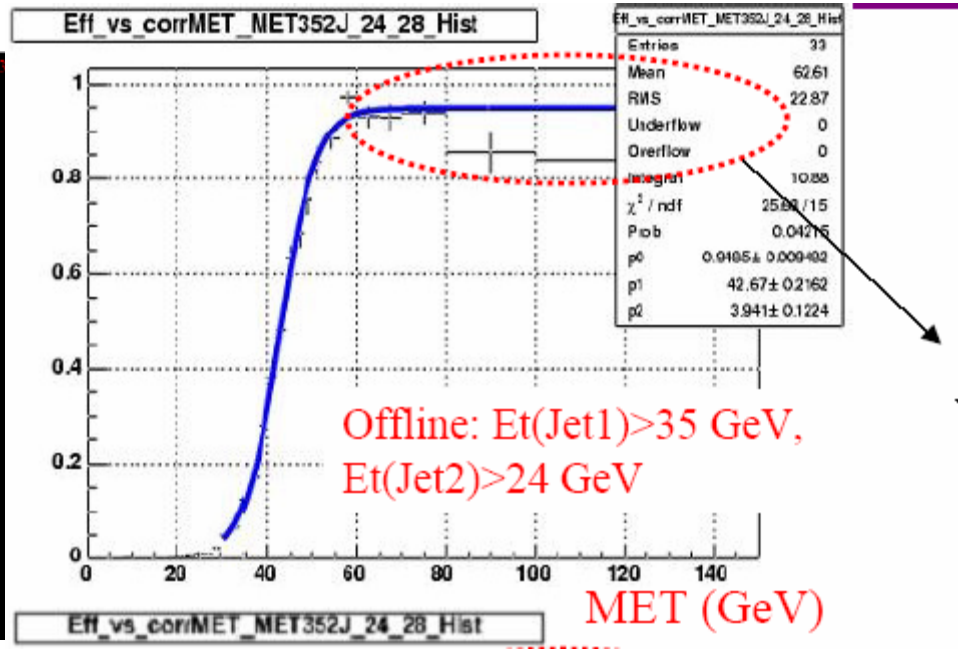
Status of jet trigger cross sections

- Increasing the L1 threshold to 20 GeV for L2_JET90 reduced the cross section, but a growth term is starting to appear again at high instantaneous luminosity
  - This highest-E_T jet trigger must stay unprescaled at all $\mathcal{L}$ for new physics searches
  - Raising L2 thresholds has been discussed
- The lower-E_T jet triggers have large growth terms and are destined to have increased prescales if nothing is done

Multi-jet trigger efficiency

- When jets are merged together into a single cluster, the efficiency for triggering on multi-jets (Higgs, top) is hurt
- The loss of efficiency for the MET+2JET trigger at high offline MET was found to be due to this

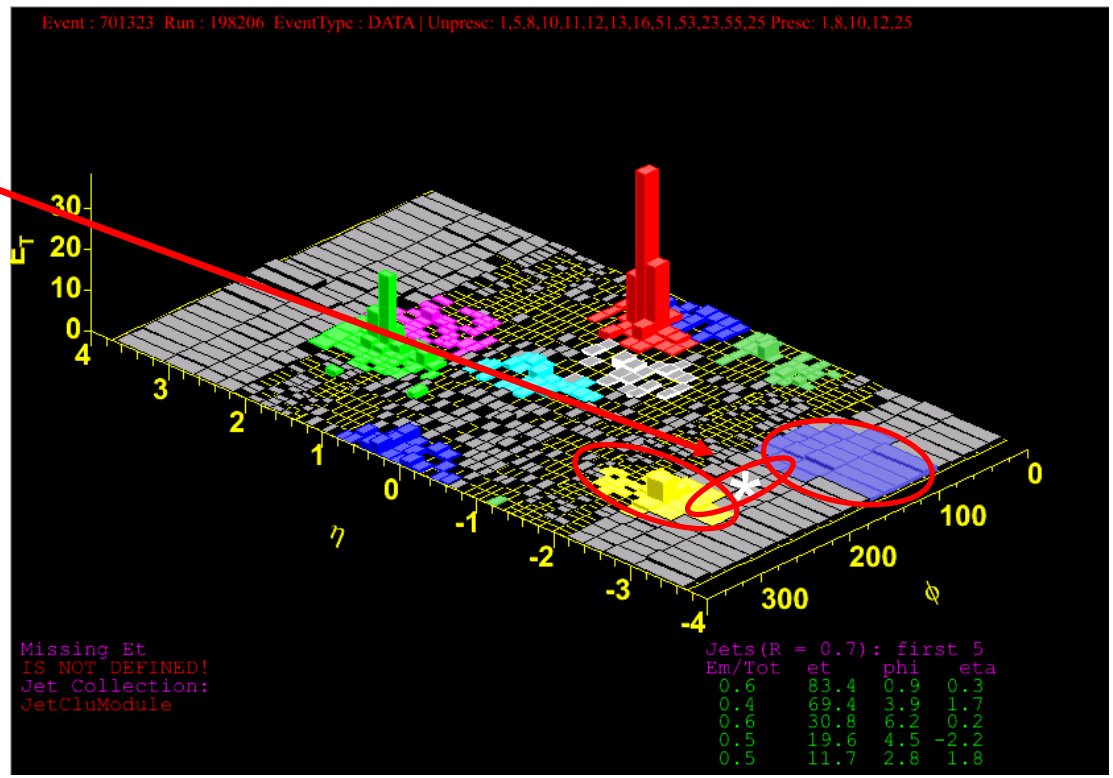




Can we fix the current clustering?

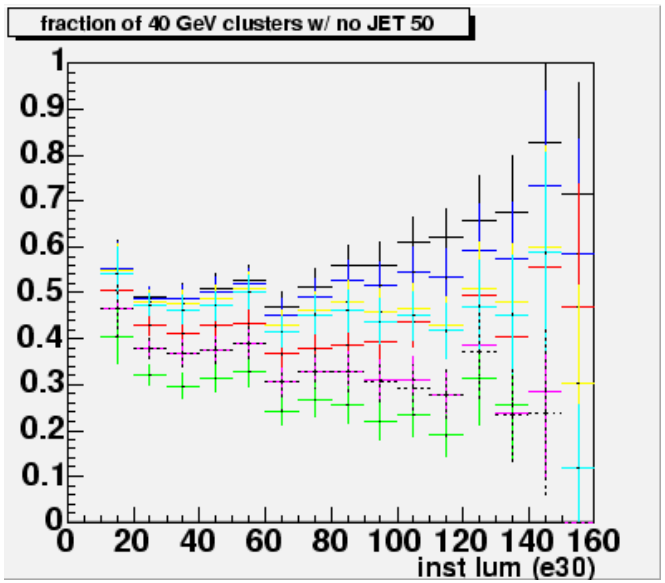
- Increasing the shoulder thresholds may break up some of the large “Pac-man” clusters

2 plug jets joined by junk at ieta=1 pass L2_JET90 (ROF is ieta=0,23)



Study of seed/shoulder threshold: removal of fake clusters

- Emulate L2 clustering with different thresholds
- Using JET_CAL_SINGLETOWER_5, looked at fraction of 40 GeV L2 clusters which do not pass L3 JET50
  - Of course many of these are valid jets with $40<E_T<50$ (flat component)
  - The rise with luminosity is what we are interested in
- Raising the shoulder threshold to 1.5 GeV seems to remove this rise (up to $\mathcal{L}$~160e30)



seed / shoulder

— 3 GeV / 1 GeV (default)
— 3 GeV / 1.25 GeV
— 3 GeV / 1.5 GeV
— 3 GeV / 2.0 GeV

— 5 GeV / 1 GeV
--- 5 GeV / 1.5 GeV
— 8 GeV / 1 GeV
— 10 GeV / 1 GeV

Study of seed/shoulder threshold: trigger efficiency

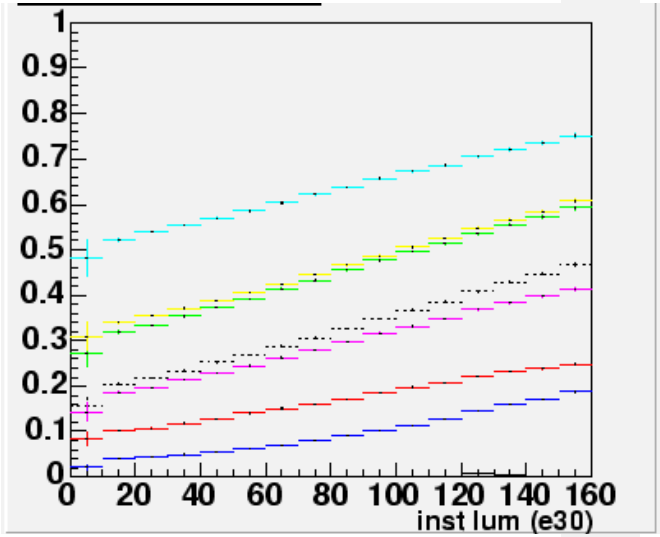
- Used Jet20,50 to see how many events are lost when thresholds are increased

→ Cuts too hard on low-E_T jets

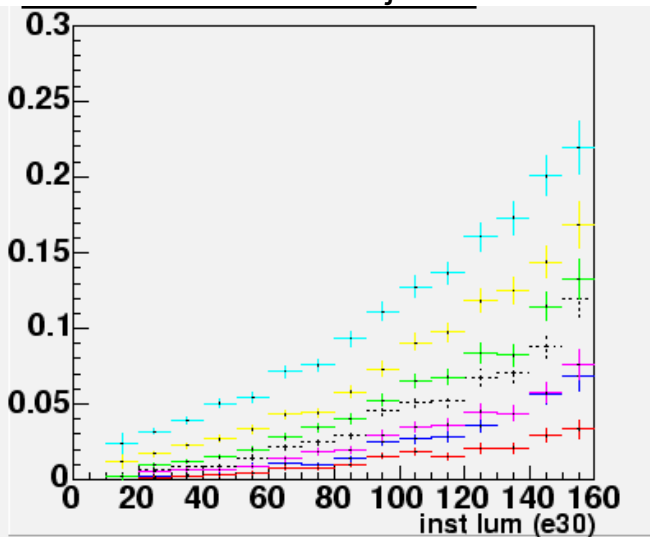
seed / shoulder

— **3 GeV / 1 GeV (default)**
— **3 GeV / 1.25 GeV**
— **3 GeV / 1.5 GeV**
— **3 GeV / 2.0 GeV**
— **5 GeV / 1 GeV**
--- **5 GeV / 1.5 GeV**
— **8 GeV / 1 GeV**
— **10 GeV / 1 GeV**

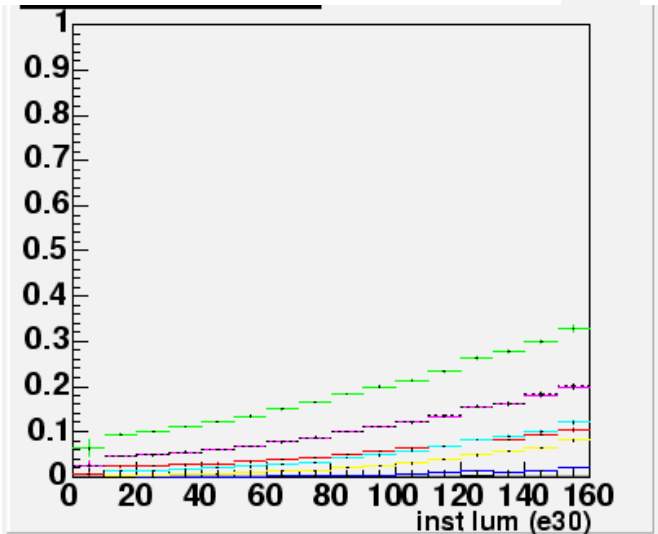
Fraction of Jet20 events lost



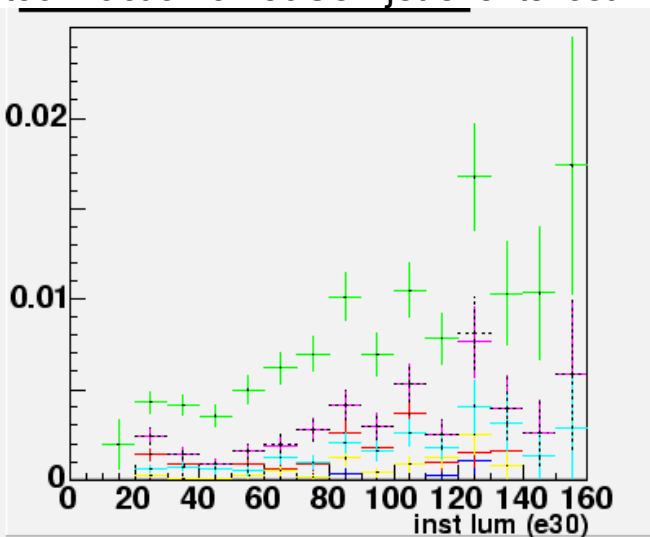
Jet20: fraction of 50GeV jet events lost



Fraction of Jet50 events lost



Jet50: fraction of 80GeV jet events lost



The current clustering cannot be made much better

- Raising the shoulder thresholds for clustering cuts the efficiency for triggering on low E_T jets (which is already not so good with the current algorithm)

- To make the fake rate a little better, the already lousy trigger efficiency is made even worse

- Let's do better!

What can we do?

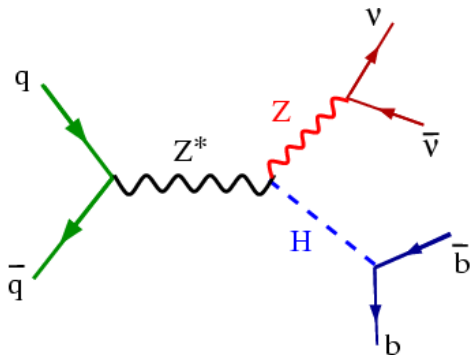
- The upgraded L2 Pulsar system offers much more flexibility than we have in the current hardware-based L2 calorimeter trigger system
- Use Pulsars to deliver the full calorimeter trigger tower information to the L2 decision CPU for processing
- Implement more sophisticated algorithms in the L2 CPU:
  - Cone-based jet clustering
  - Recalculate MET instead of just using L1_MET at L2
  - Can also do isolation, sumET etc
  - Calculate other calorimeter-based quantities such as dijet mass, $\Delta\phi$ between jets or between jet and MET, H_T, better jet-SVT matching for *b*-jets, combine with upgraded XFT for possible improvement for τ's

What we gain

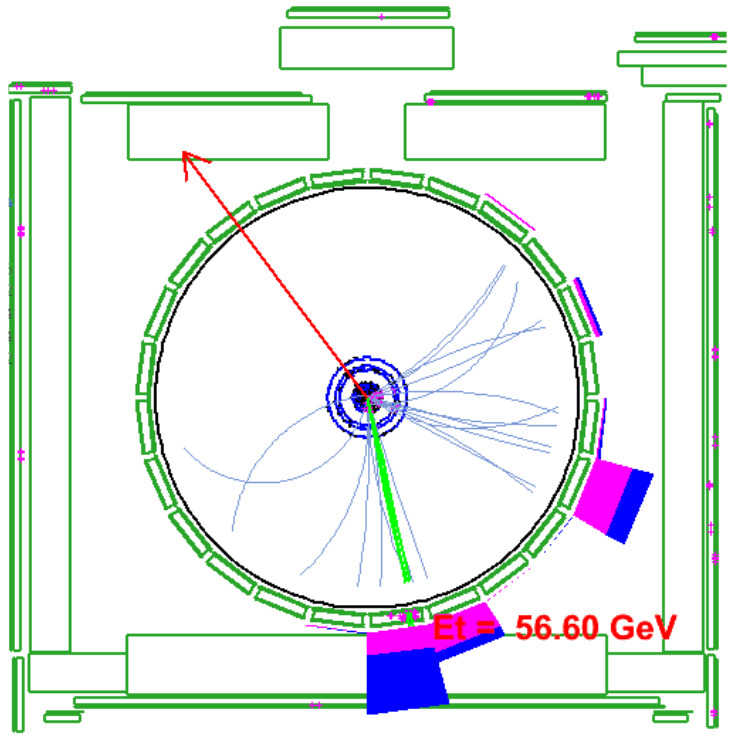
- Better purity and also efficiency of jet and MET triggers
  - Cross sections manageable at the highest luminosities
  - Most notably Higgs/SUSY MET+2JET trigger
- Bonus
  - Extra information at L2 can be used to improve triggers, increase Higgs sensitivity

A few words on $ZH \rightarrow \nu\nu bb$

Higgs search in the MET + JETS signature ($ZH \rightarrow \nu\nu bb$ and $WH \rightarrow l\nu bb$)



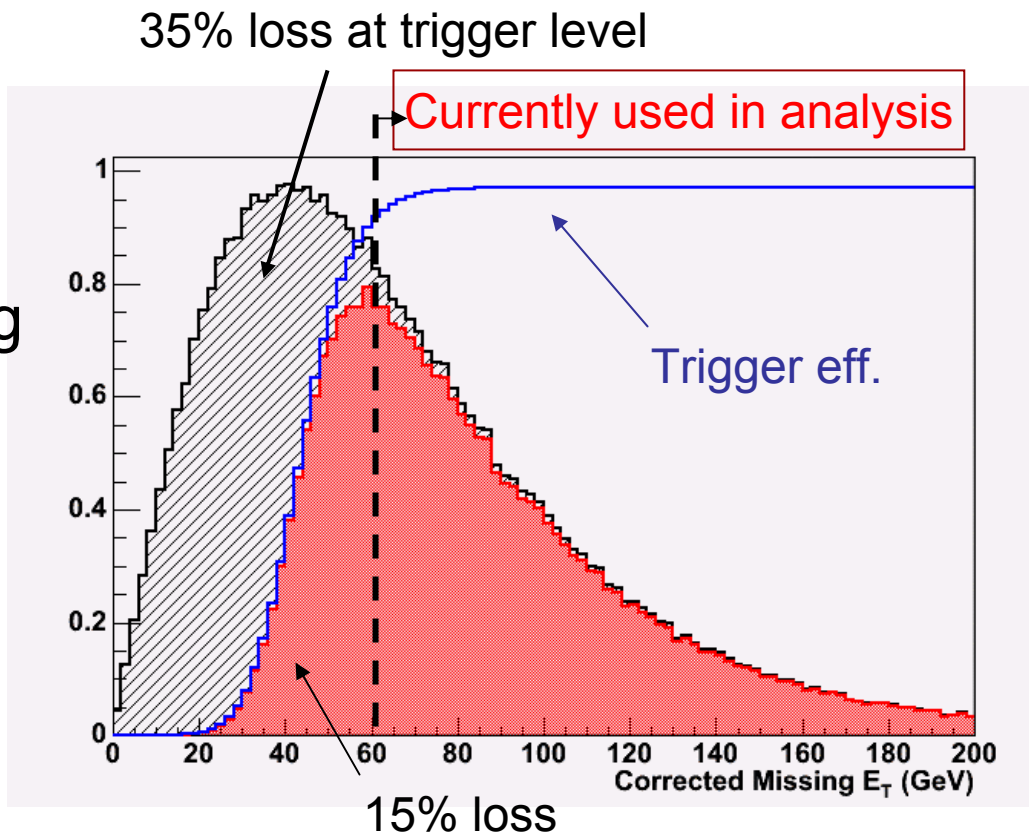
- Signal has a distinctive topology
  - Large $\not{E}_T$
  - Two jets (one is b-tagged)
- Trigger (**MET35 + TWO JETS**)
  - Missing E_T > 35 GeV
  - Two jets E_T > 10 GeV



A data-event from the ZH analysis in 2005

Trigger cross section vs. efficiency

- MET35_&_CJET_&_JET and MET45 triggers are very important for many Exotics searches, including the SM Higgs in the *ZH* channel
- Need a relatively low MET trigger for these analyses
- The trigger rate is a problem, but raising the MET threshold would hurt the search sensitivity



Corrected Missing E_T of the SM Higgs $ZH \rightarrow \nu\nu bb$, M_H=120 GeV (arbitrary normalization) – demonstrates our current trigger limitations

Improving the signal yield for $ZH \rightarrow \nu\nu bb$

- What could we trigger on:
  - Requires a low MET threshold: <MET> = ~ 70 GeV
  - Two jets (1 may be central)
  - *b*-jet (trigger level track-cluster matching)
- *b*-jet requirement has been tested in the MET_BJET trigger with limited success in terms of the trigger-rate

Have already tried many things

- Main problem with the trigger is due to QCD dijet events:
  - Large fraction of passing events are QCD
  - The MET in the QCD events is "fake" caused by detector effects – difficult to describe it even at analysis level
  - Trigger efficiency different for events with intrinsic MET (ZH or EWK processes)

$\Delta\phi$ between MET and jet

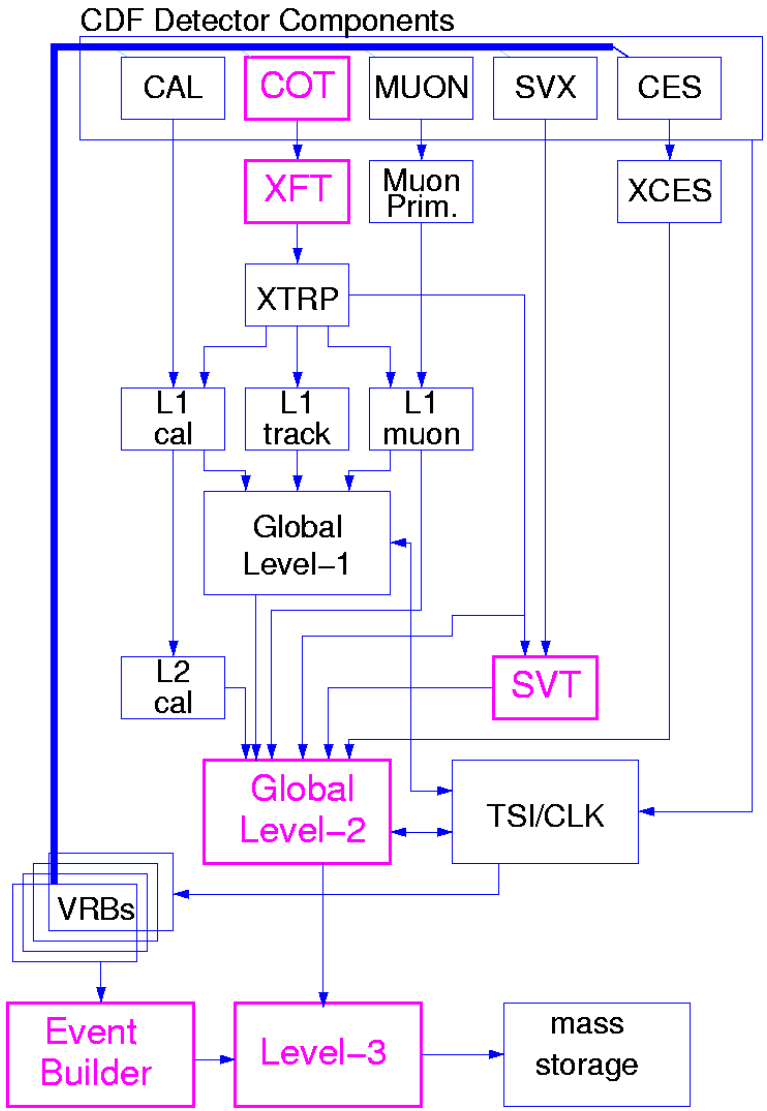
- This effect is more evident in the L1 MET than in the L3 MET "turn-on" plots when they are calculated from jet- and muon-rich events
  - Need to improve the resolution of MET at L1 and/or L2

Improve L2 MET resolution

CDF trigger performance at high luminosity

CDF trigger system

- Level 1
  - Custom designed hardware
  - L1A: data to buffers in FE, subset of data to L2
- Level 2
  - Custom hardware + commodity processor
  - L2A: all data to L3
- Level 3
  - Processor farm
- Run IIb upgrades
  - Pulsar global L2 decision (speed)
  - SVT (Pulsars) (speed)
  - XFT (purity)
  - L3 / event builder (increase bandwidth downstream of L2)

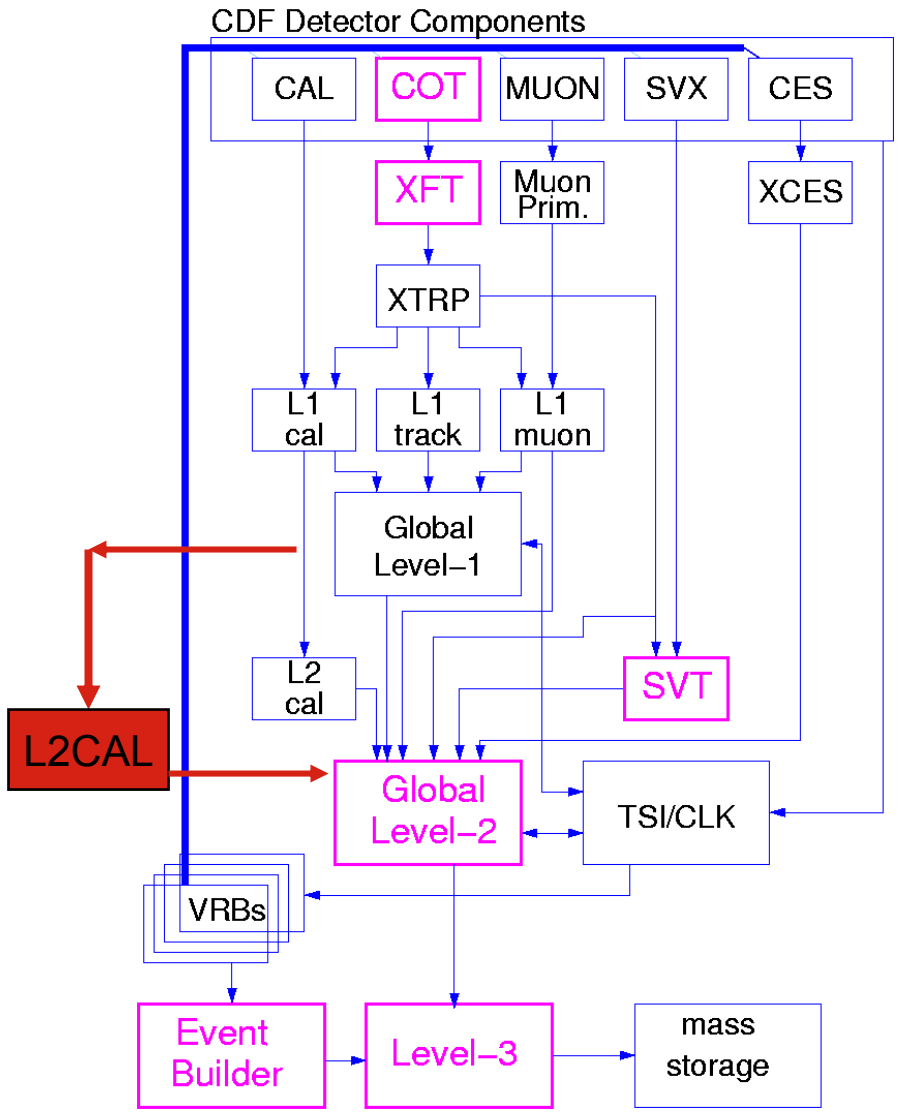


Trigger performance at high luminosity

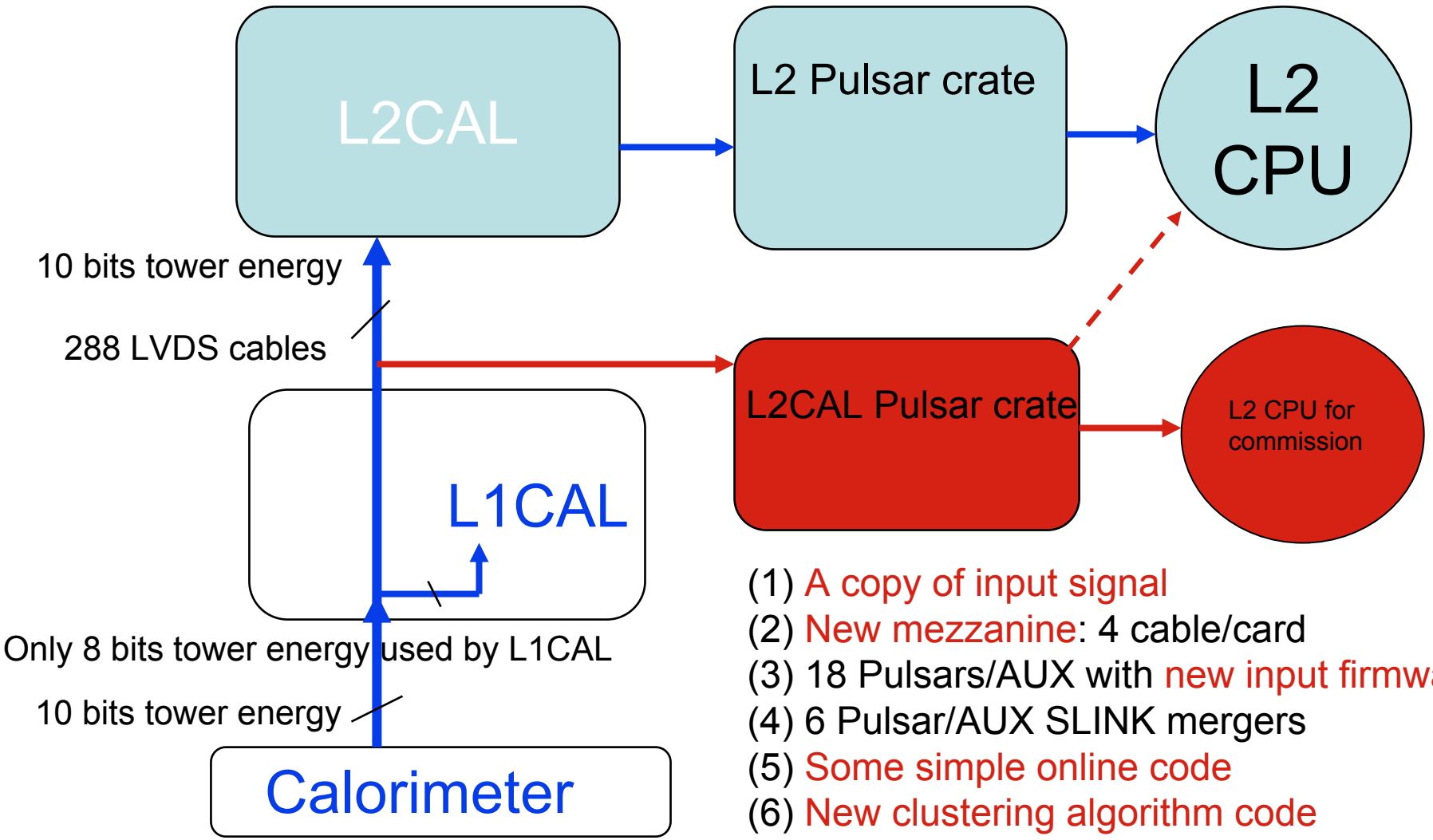
- $\mathcal{L}$~180E30: L2A limited to ~800Hz
- L2 cross sections growing rapidly with $\mathcal{L}$
  - CMX
    - Being addressed with XFT upgrade
  - Jet/MET
    - Proposal addresses this
  - Backup triggers
    - Control samples for important high-p_T physics
    - Large growth term by nature
    - Rates will dominate at highest luminosities

L2CAL

- Existing L2CAL
  - 86 9U VME boards in 6 crates with custom P3 backplane:
  - 72 DCAS
  - 6 LOCOS
  - 1 CLIQUE
  - 6 IsoPick
  - 1 IsoClique
- Proposed L2CAL upgrade:
  - 18 Pulsar receiver boards
  - 6 SLINK Pulsar merger boards
  - 18 mezzanine cards (new) to receive signals from Dirac
  - Processing done in L2 decision CPU



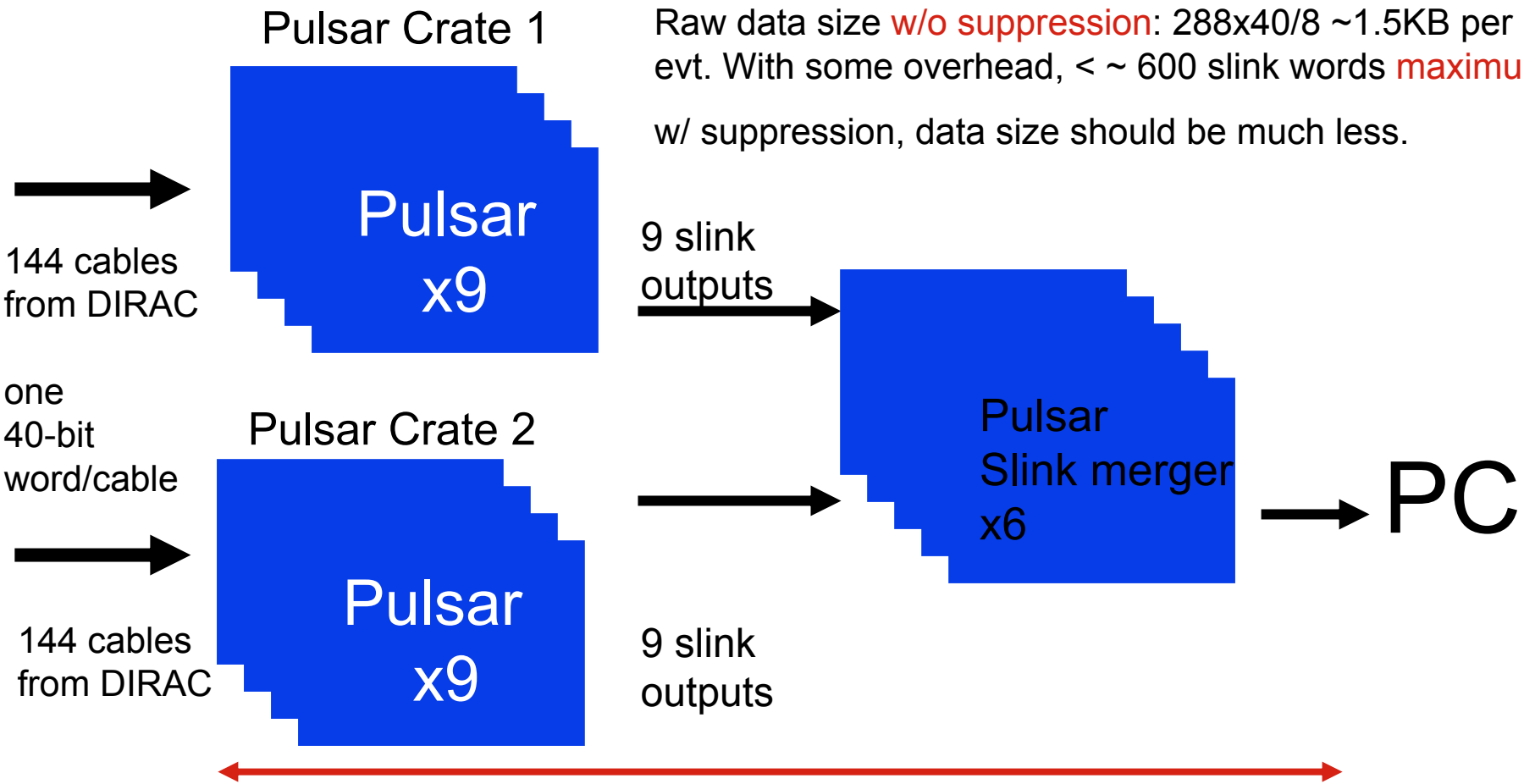
Concept of L2CAL upgrade



(1) A copy of input signal
(2) New mezzanine: 4 cable/card
(3) 18 Pulsars/AUX with new input firmware
(4) 6 Pulsar/AUX SLINK mergers
(5) Some simple online code
(6) New clustering algorithm code

Pulsars for L2CAL

(1 Pulsar: 4 mezzanine x 4 cable = 16) x 18 = 288 input cables total



Data transfer latency after L1A: is expected to be on average within ~10 us
Note: unlike other L2 paths, CAL data already available at L2 input upon L1A

Implementation

- Use existing Pulsar hardware
  – and also experience
- Need to design and produce mezzanine card
- Expect ~6 months for hardware, firmware, software, installation… ~few months to fully make use of in official trigger table
- Commissioning done parasitically (as for L2 Pulsar upgrade) so little impact on data-taking

Impact on physics analysis

- Use of existing triggers
  - Studies of trigger efficiencies will have to be repeated
  - This will be necessary for the higher luminosity data even without changes to the current system
  - Efficiencies are expected to be improved and more stable against luminosity
  - Can emulate old/new trigger to understand any differences in dataset before/after upgrade
- Additional efforts to improve triggers by taking advantage of the new possibilities allowed by this upgrade could be well worthwhile
  - Higgs sensitivity

Outline of following talks

- Expected physics performance of the upgraded L2 jet and MET triggers
  - Gene's talk
- Proposed L2CAL upgrade hardware configuration, implementation, performance
  - Laura's talk
- Summary
  - Ted's talk

L2 Jet triggers

Trigger	Cross section (nb)		
	100E30	200E30	300E30
Higgs high-p_T b-jet (loose) L2_BJET15_D120_DPS	160	DPS	
Higgs high-p_T b-jet L2_BJET15_D120_JET10_ETA1.8	56	316	866
$(W/Z \rightarrow \text{dijet}) + \gamma$ L2_CEM12_ISO_&_SUMET20_&_TWO_JET3_ETA1.8	82	68	53
SUSY searches, Higgs L2_CJET10_JET10_L1_MET25_&_MET35_&_CJET_&_JET	136	867	2461
$\mu\tau$ for Higgs and exotic searches L2_CJET15_L1_BMU10_BSUR_TSUO	15	49	117
top multi-jet L2_FOUR_JET15_SUMET175	5	16	41
QCD jet studies, jet energy/resolution, b-tag studies, backup L2_CJET15_PS24 L2_JET15_PS25 L2_JET40 L2_JET60	 18 39 28 21	 37 94 147 53	 73 202 411 120
new physics searches L2_JET90	25	42	79
high-p_T b-jet (loose) L2_TWO_JET15_ETA1.5_&_TWO_TRK2_D100_DPS	440	DPS	
$\not\!\!E_T + b$-jet ($ZH \rightarrow \nu\nu b\bar{b}$, SUSY, leptoquarks) L2_TWO_TRK2_D100_&_BJET15_&_MET15_DPS	240	DPS	
Higgs Multi-jet L2_TWO_TRK2_D120_&_THREE_JET10_SUMET90_DPS	90	DPS	
b-jet energy scale and resolution for top mass, Higgs L2_Z_BB_BJET_OS L2_Z_BB_BJET_SS	 24 18	 lum enable 150 lum enable 150	